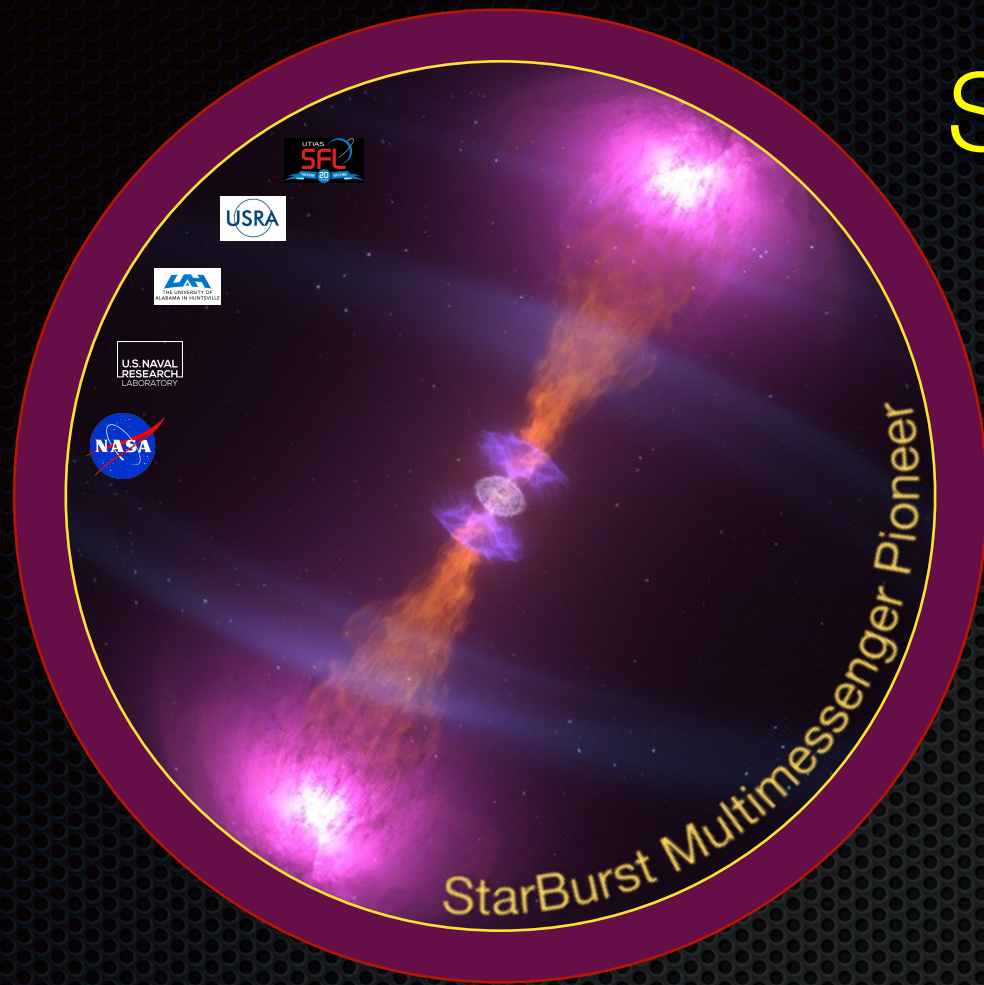
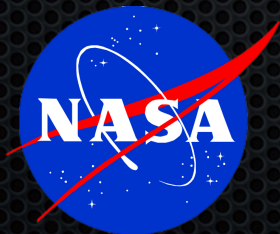


StarBurst Multimessenger Pioneer



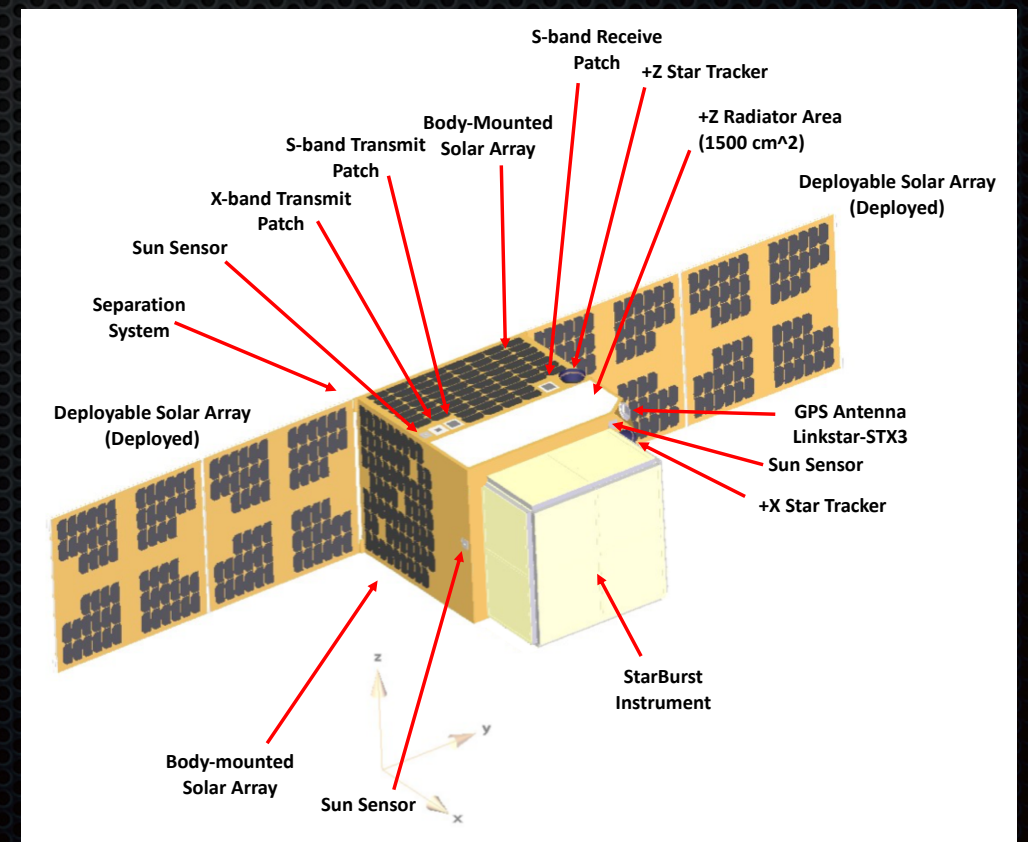
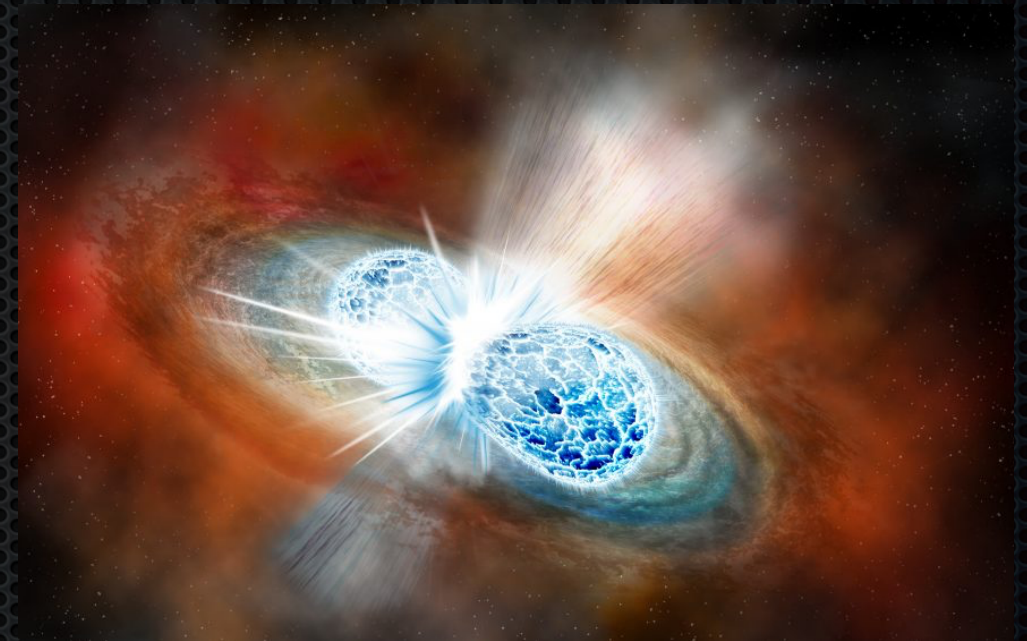
P.I. Daniel Kocevski

Marshall Space Flight Center

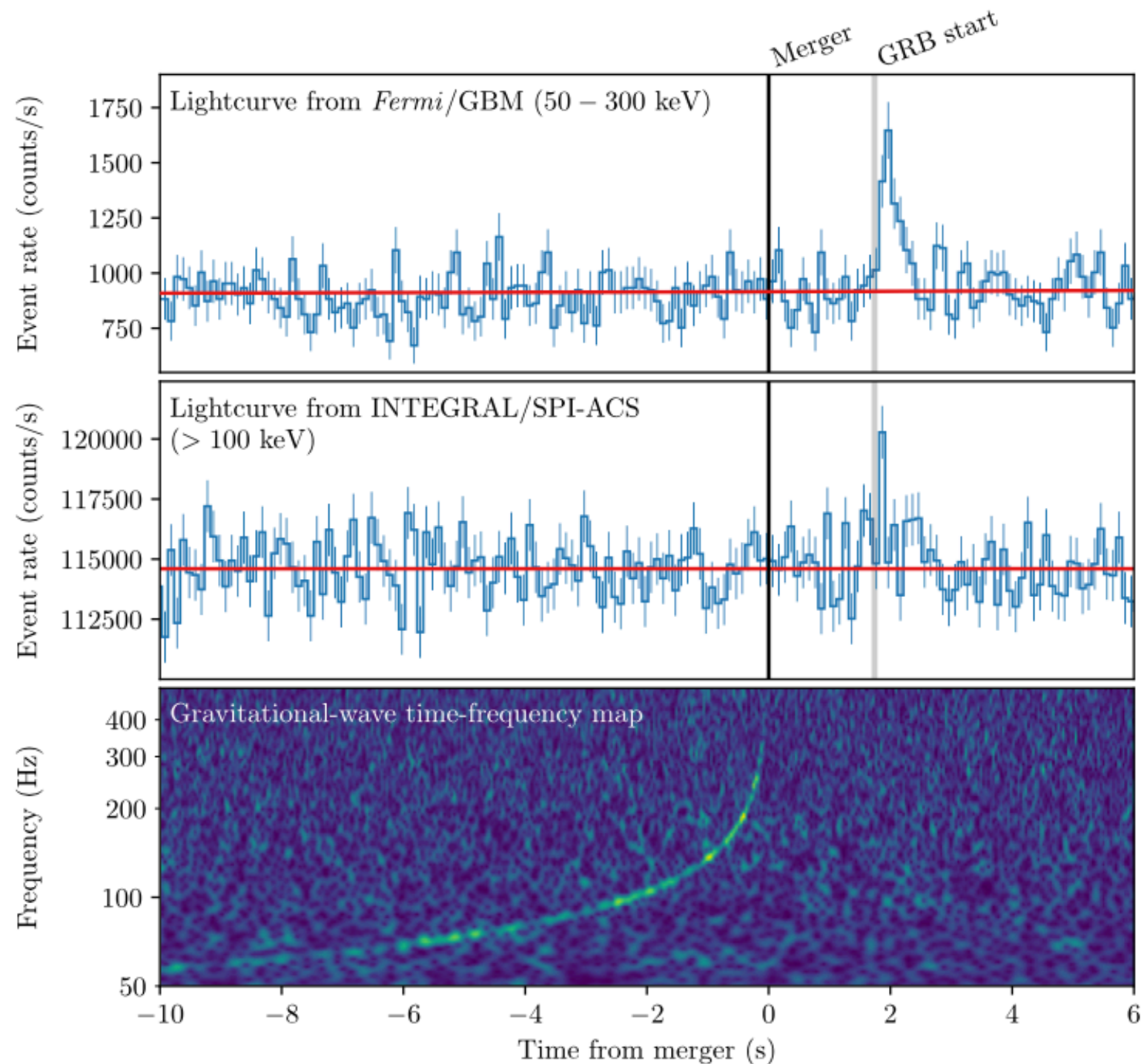


StarBurst Multimessenger Pioneer

- ESPA-Grande SmallSat to detect a large sample of SGRBs coincident with GW detections
- Marshall Space Flight Center, Naval Research Lab, and the University of Toronto's Space Flight Laboratory
- Nominal launch in 2025 for a 1-2 year mission to coincide with LIGO A+
- Science Objectives:
 - 1) Constrain the progenitors of SGRBs
 - 2) Probe the remnants of NS mergers
 - 3) Constrain the neutron star equation of state
 - 4) Probe the structure of relativistic outflows produced in neutron star mergers



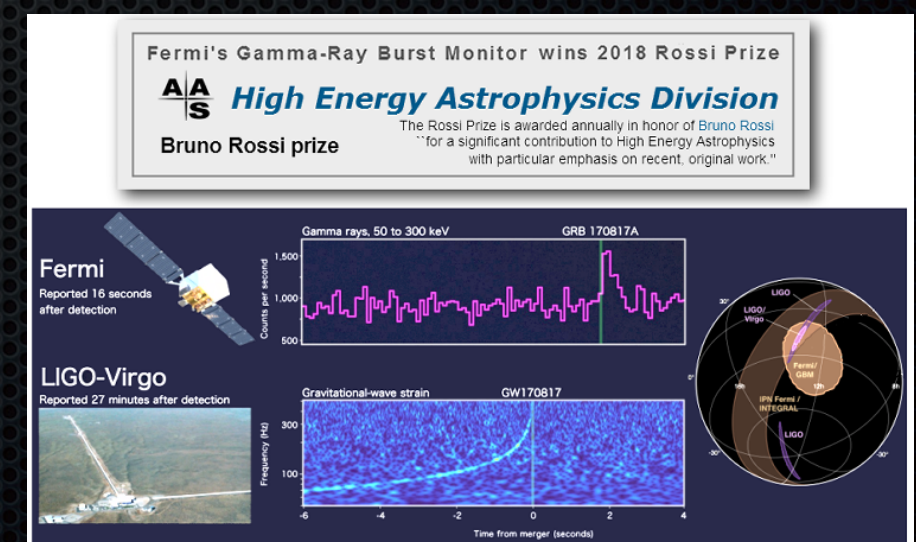
GW170817 - First Joint GW/GRB



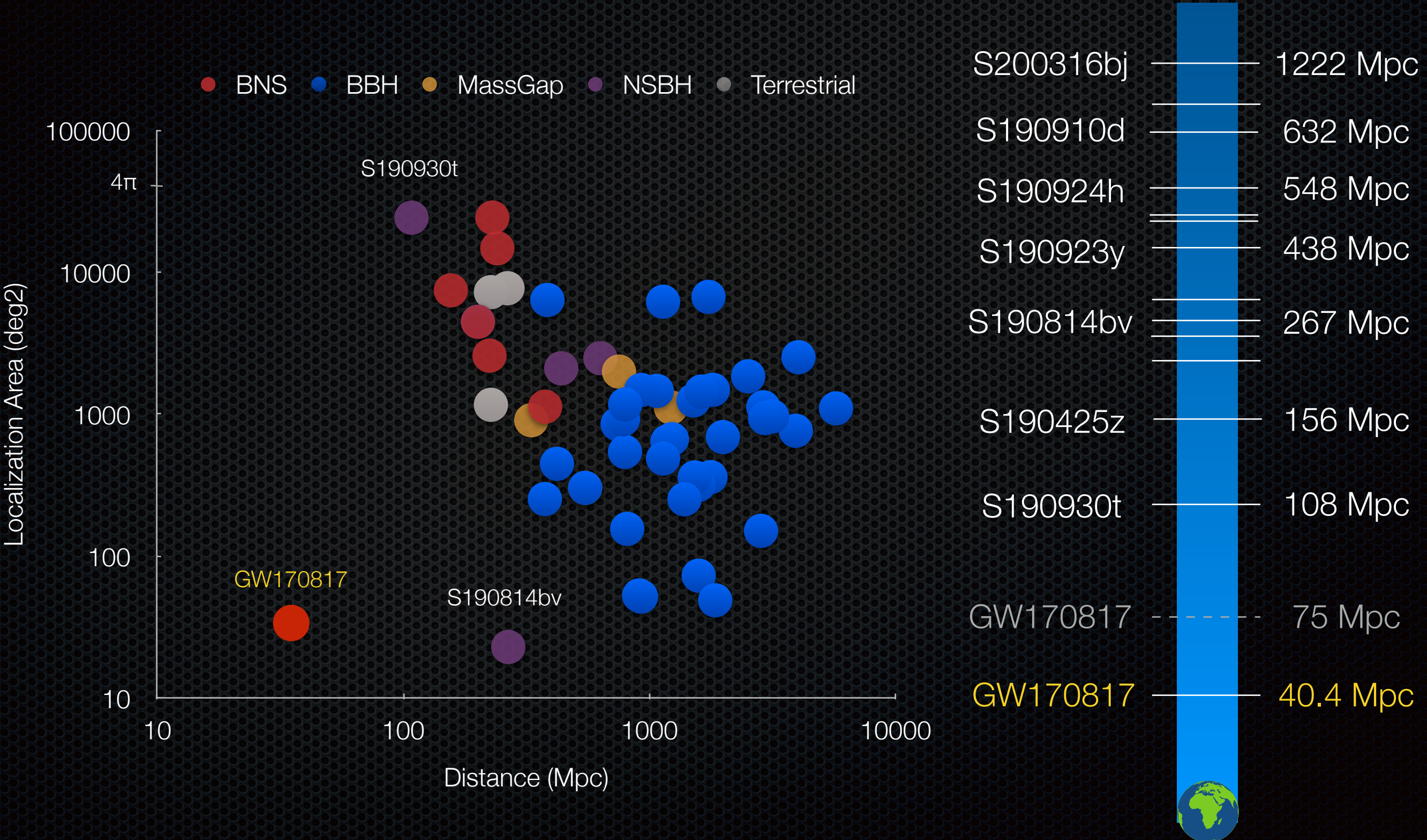
Abbot et al. 2017

GRB 170817A

- First joint detection of a SGRBs in gravitational waves and gamma-rays occurred on August 17, 2017
- More than 3000 papers have been written on this one event!
- Science enabled by 170817
 - Origin of SGRBs
 - Speed of gravity (Fermi)
 - Hubble consent (HST)
 - Neutron star equation of state (Fermi, HST, Swift)
 - Relativistic jet formation and structure (Fermi)
 - Heavy element production in the Universe
- Colleen Wilson-Hodge and the GBM team received the AAS 2018 Rossi price for the work

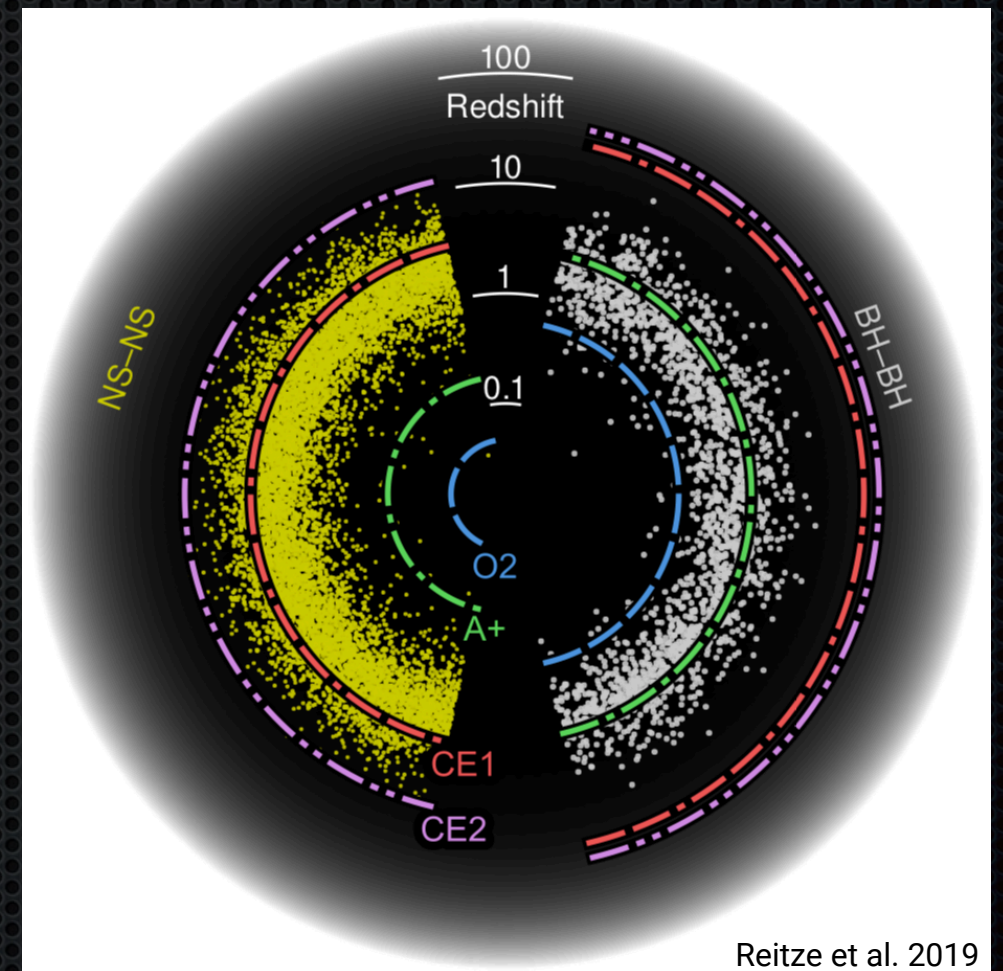


BNS/BHNS Events in O2 & O3



GW Network Landscape

Observing Run	Timescale	BNS Rate (yr ⁻¹)	BNS Range (Mpc)	Redshift
O1: LIGO	2015-2016	0.05-1	80	0.02
O2: LIGO/Virgo	2017-2018	0.2-4.5	100 / 30	0.02
O3: LIGO/Virgo	2019-2020	0-13	110-130 / 50 / 8-25	0.03
O4: LIGO/ Virgo/ KAGRA	2021-2023	0.6-62	160-190 / 90-120	0.04
O5 (A+): LIGO/ Virgo/ KAGRA/India	late-2024+	10-200 / >30	330 / 150-260 / 130+	0.07
Voyager	~2030?	>daily	1000	0.4
Cosmic Explorer 1	2035-2040	>hourly	>10,000	1.4
Cosmic Explorer 2	~2045	>hourly	All	10



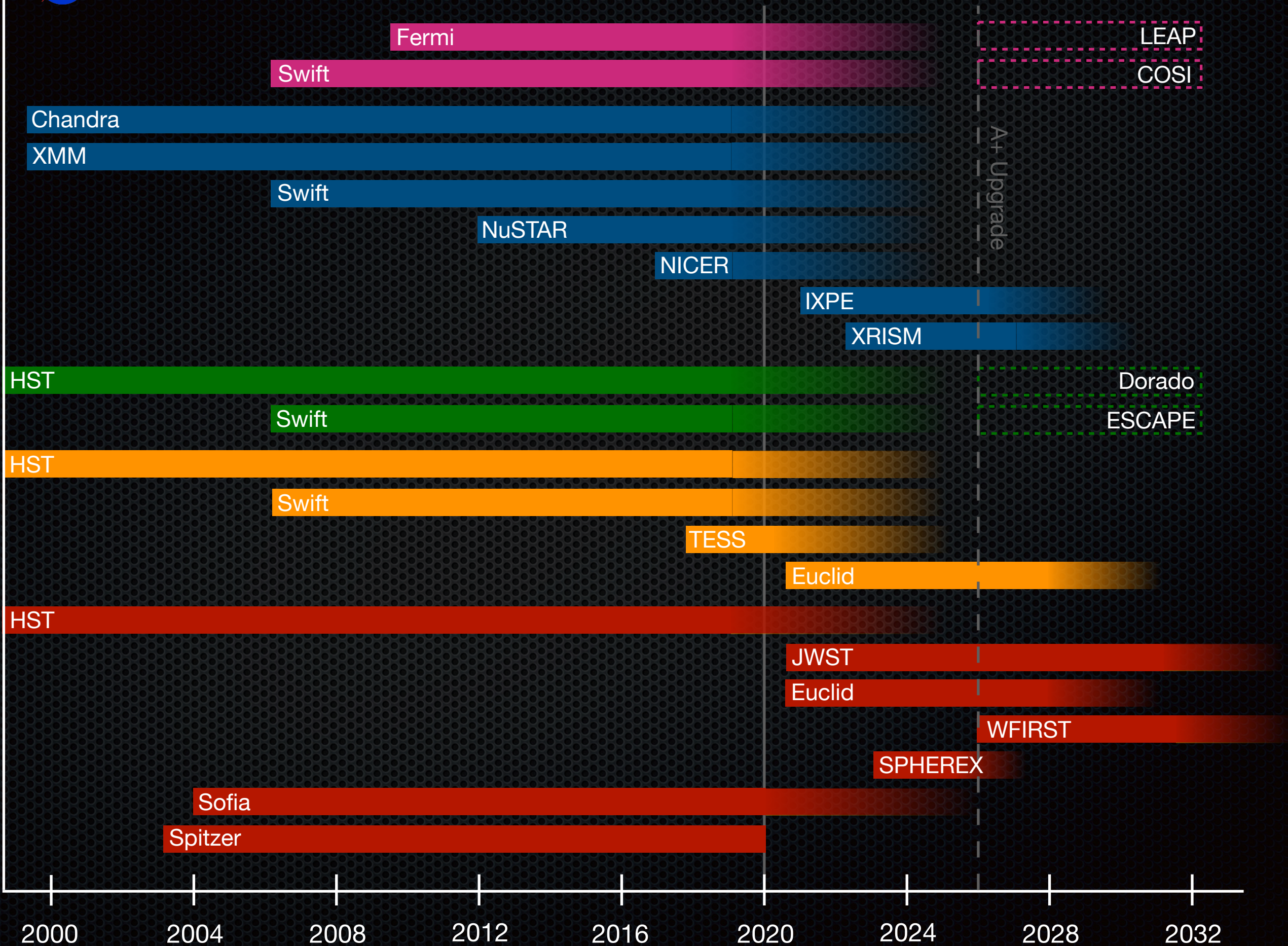
Predicted Source Population

- The start of the “A+” configuration should see a large increase in the rate of BNS mergers
- Clear need for an large area all-sky gamma-ray detector in the keV energy range

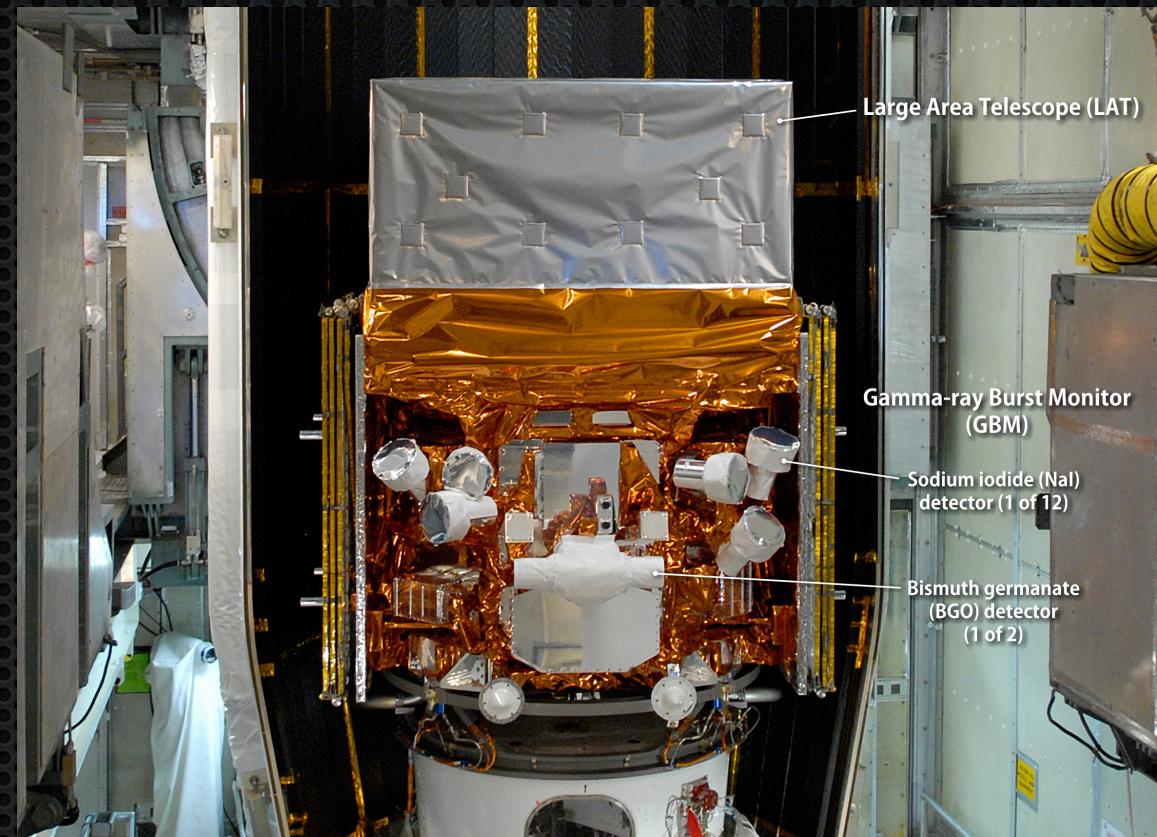
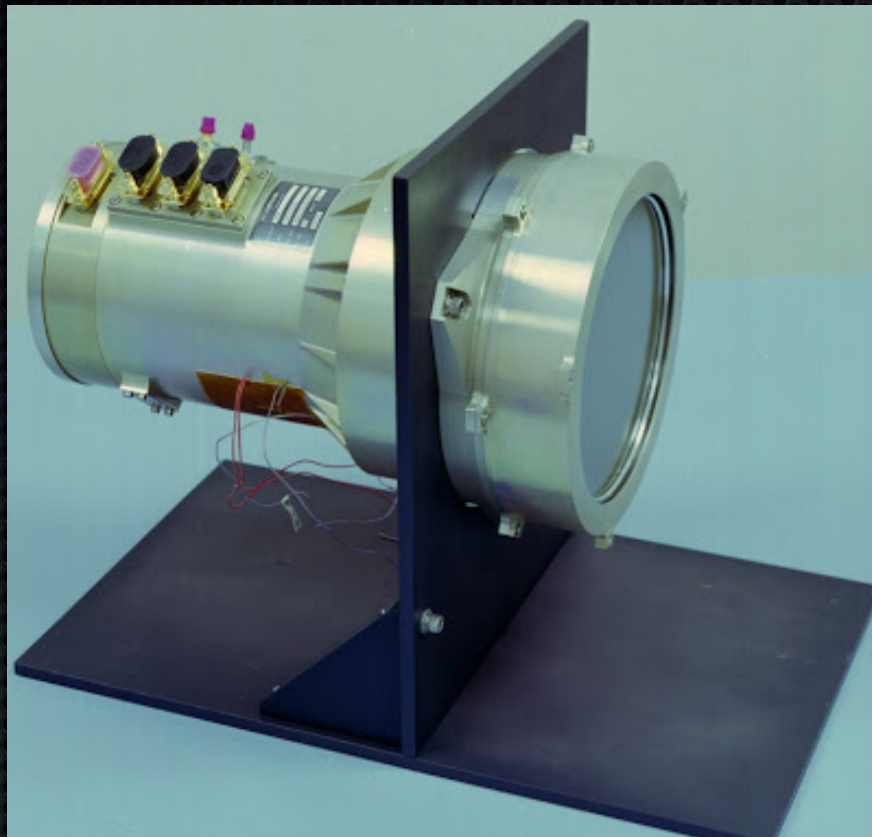


NASA Astrophysics Mission Landscape

Gamma-ray
X-ray
Ultraviolet
Optical
Infrared

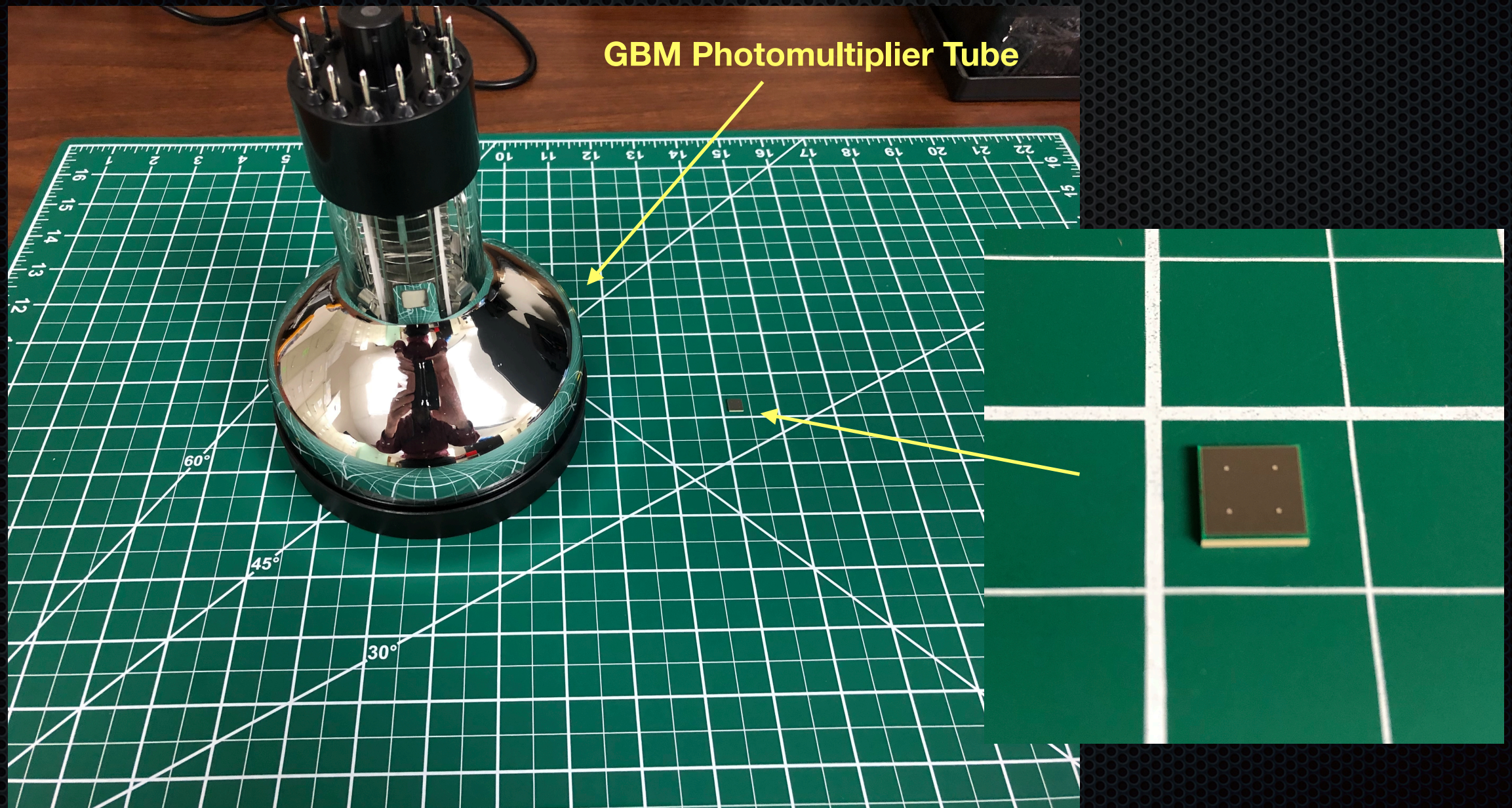


Expanding Upon the Success of Fermi GBM



- Fermi Gamma-ray Burst Monitor was designed in the 2000s as a secondary instrument
- Fermi-GBM consists of NaI scintillator crystals attached to photomultiplier tubes
- All of the GBM detectors combined have a mass = 54.5 kg
 - Compared to an ESPA-Grande mass limit of 465 kg

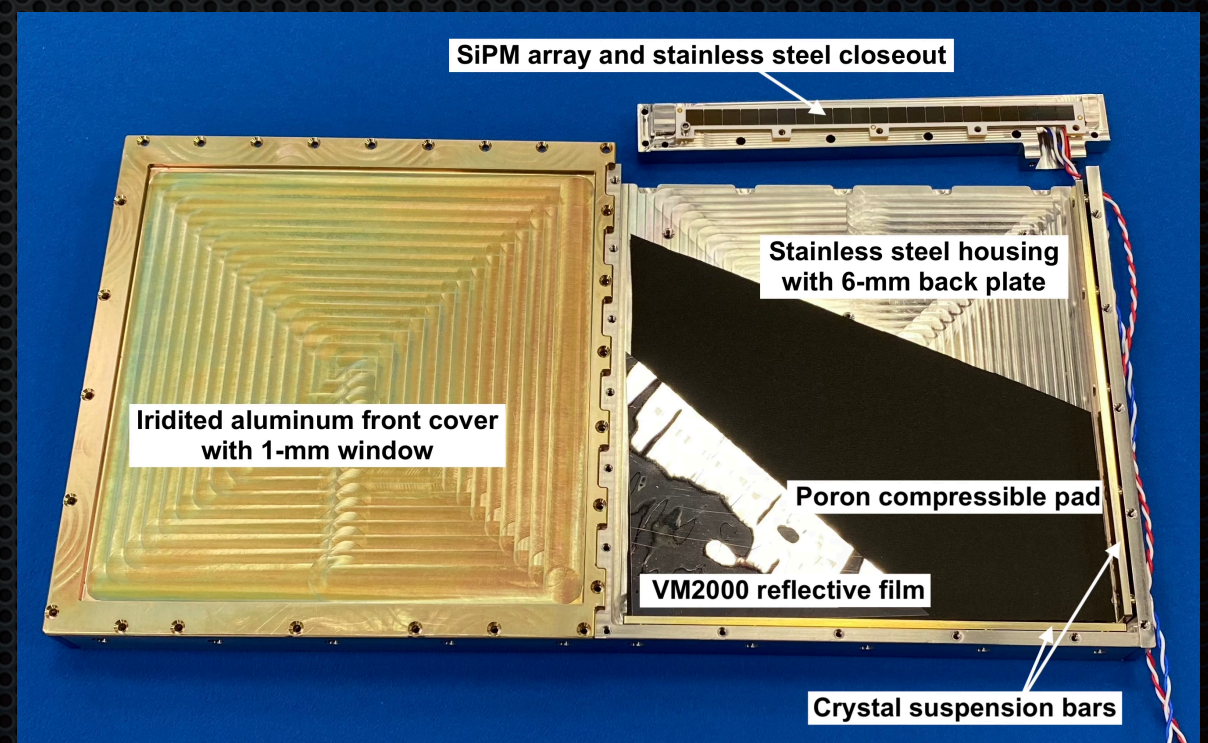
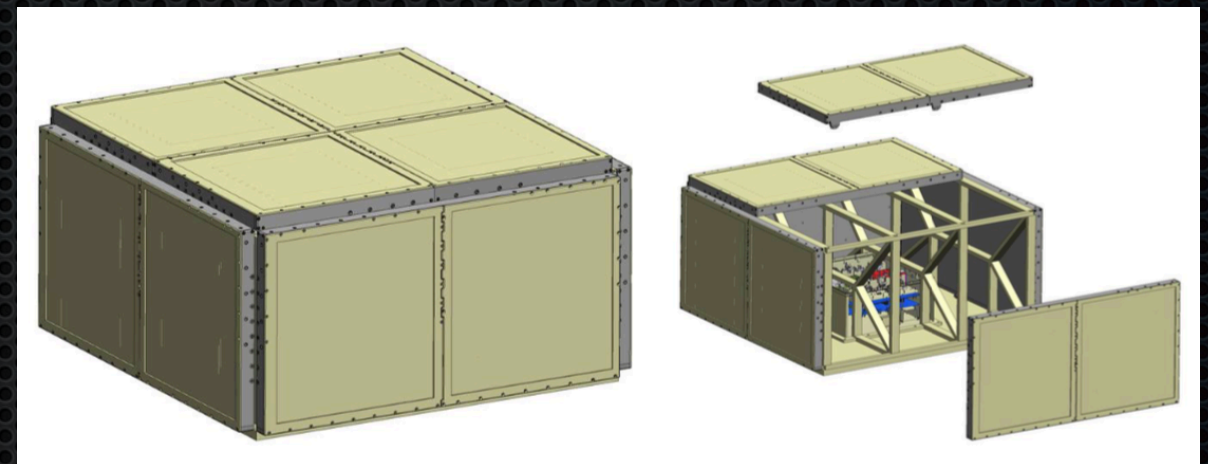
GBM Photomultiplier Tube vs SiMP



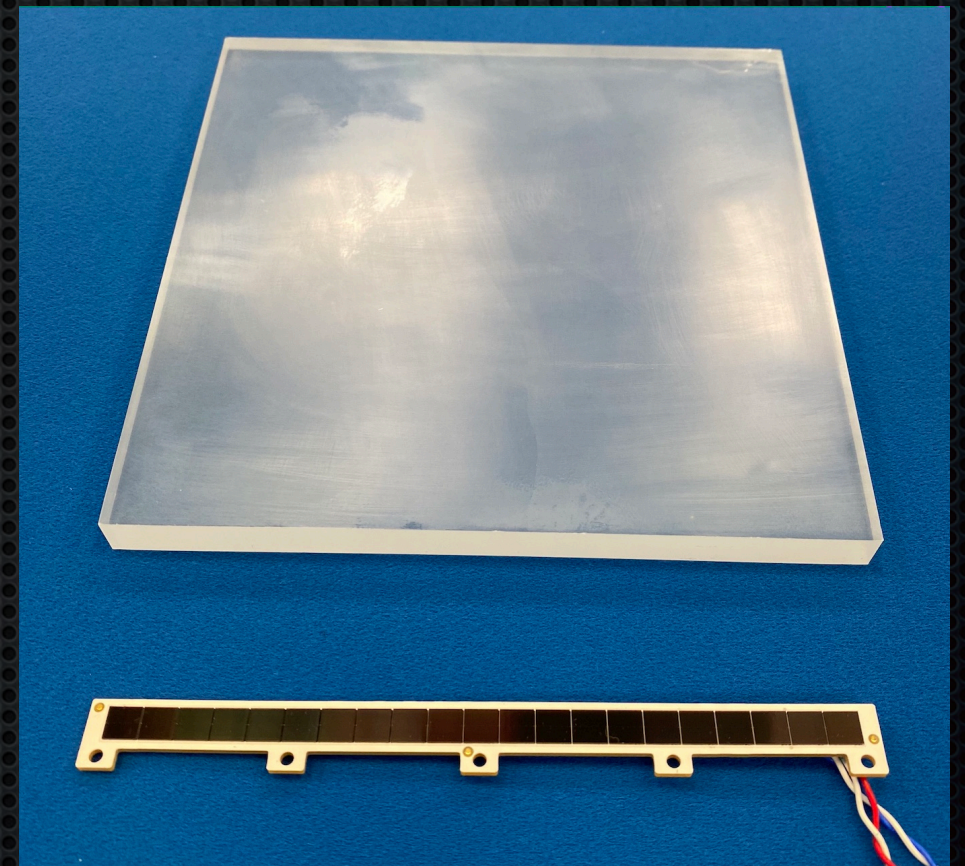
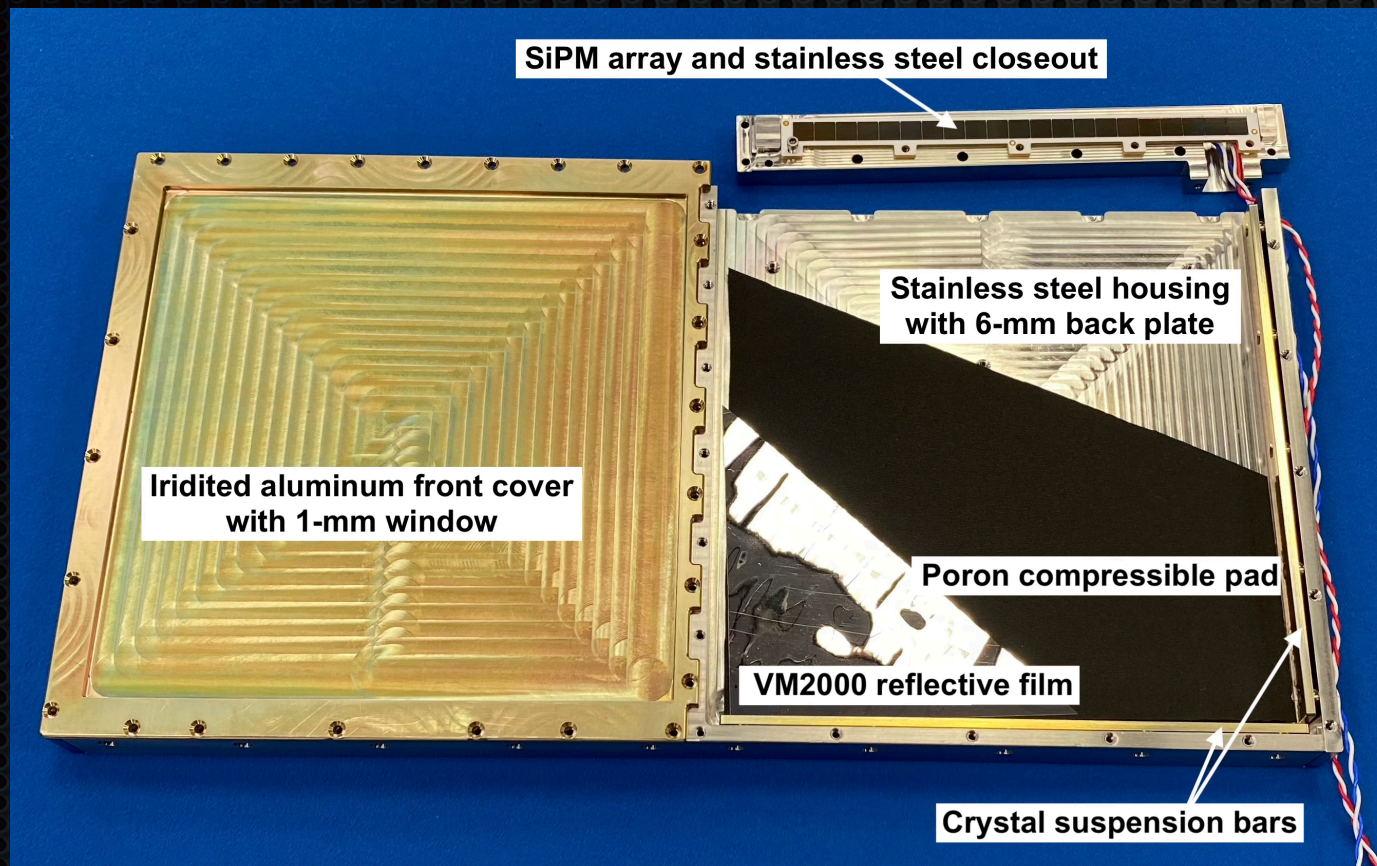
- Silicon Photomultipliers (SiPMs) allowed for a further weight reduction and lower power usage

StarBurst Instrument and Bus

- Instrument built by Naval Research Lab (NRL)
 - Based on the Glowbug ISS payload (APRA)
 - 12 CsI scintillation detectors
 - Sensitive to 30-2000 keV energy range
 - Crystal size: 27 cm x 27 cm
 - Instrument payload: 58 cm x 58 cm x 29 cm
 - Instrument mass: ~150 kg
- Spacecraft bus provided by Space Flight Laboratory (SFL)
 - ESPA-Grande DAUNTLESS platform
 - Spacecraft mass: ~135 kg
- Combined Mass: 285.6 kg



StarBurst Detector



Glowbug flight unit detector assembly, crystal, and SiPM array

StarBurst Performance

- ✦ Instrument Performance:

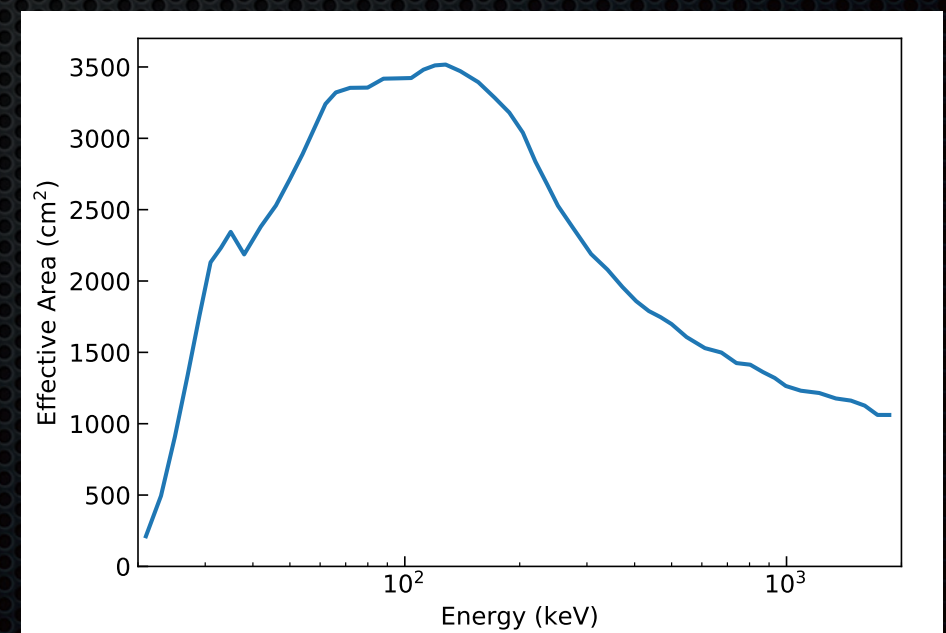
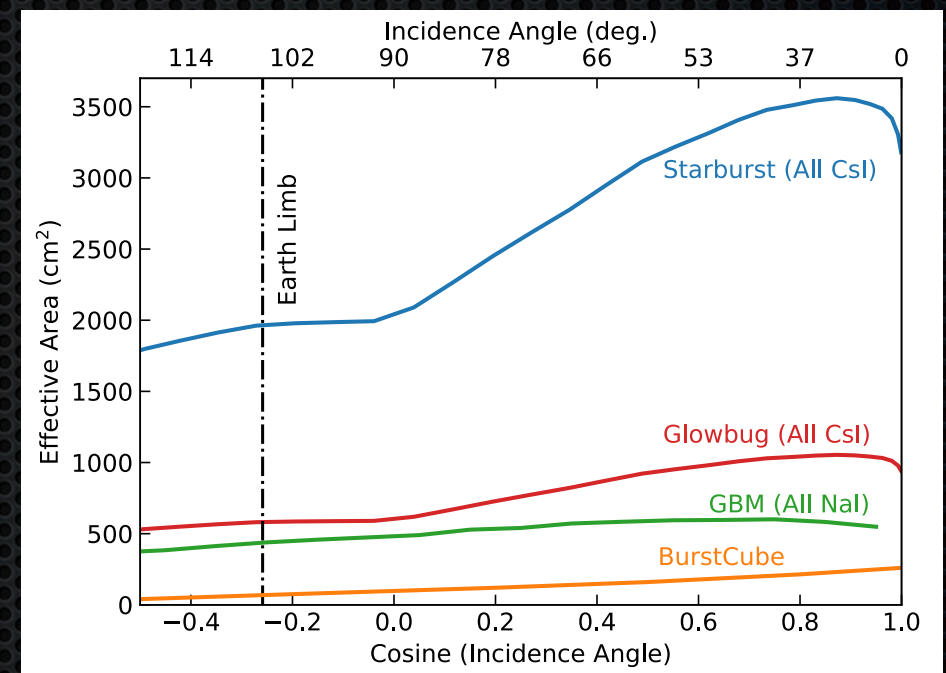
- ✦ Azimuth average effective area peak of $\sim 3500 \text{ cm}^2$
- ✦ GBM @ $\sim 600 \text{ cm}^2$ and Glowbug @ $\sim 1100 \text{ cm}^2$

- ✦ Detection Rate:

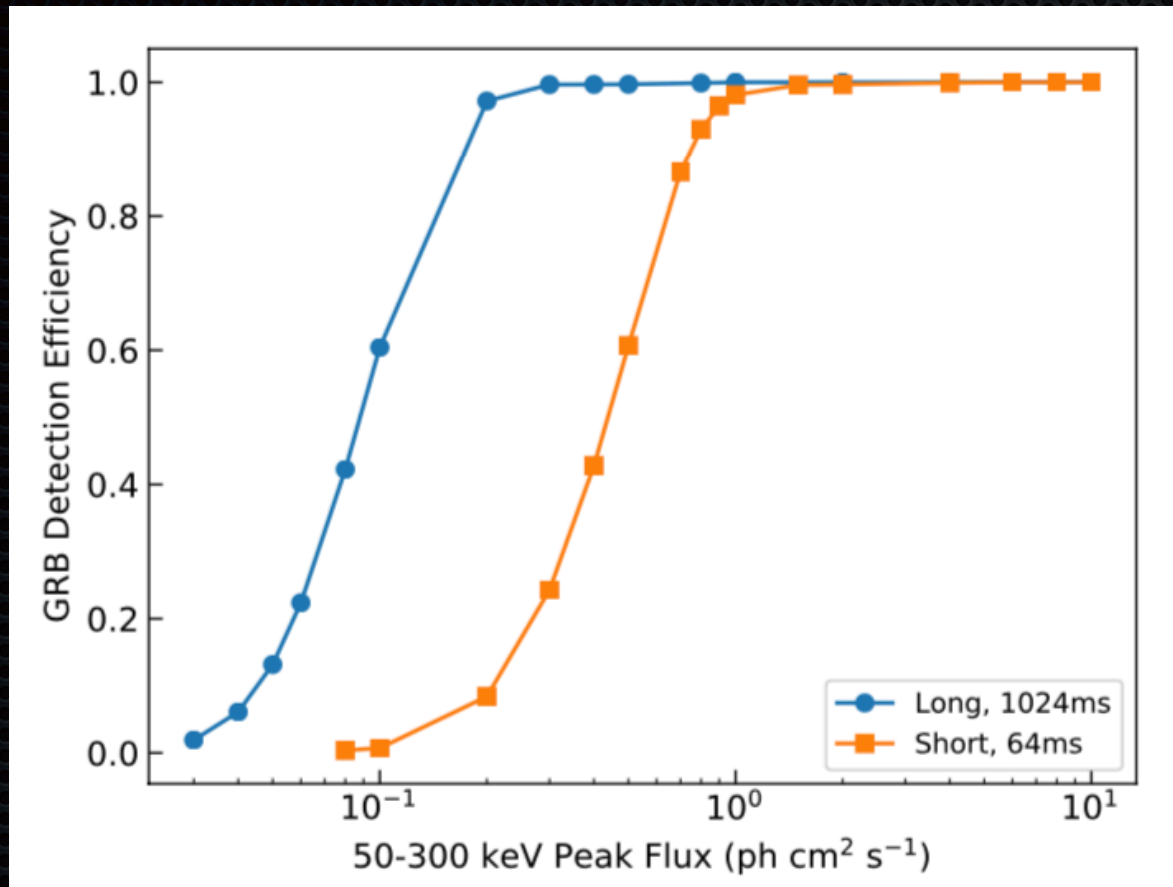
- ✦ StarBurst: 200 SGRBs/yr
- ✦ Swift: 8.6 SGRBs/yr, GBM: 40 SGRBs/yr

- ✦ Joint Detection Rate:

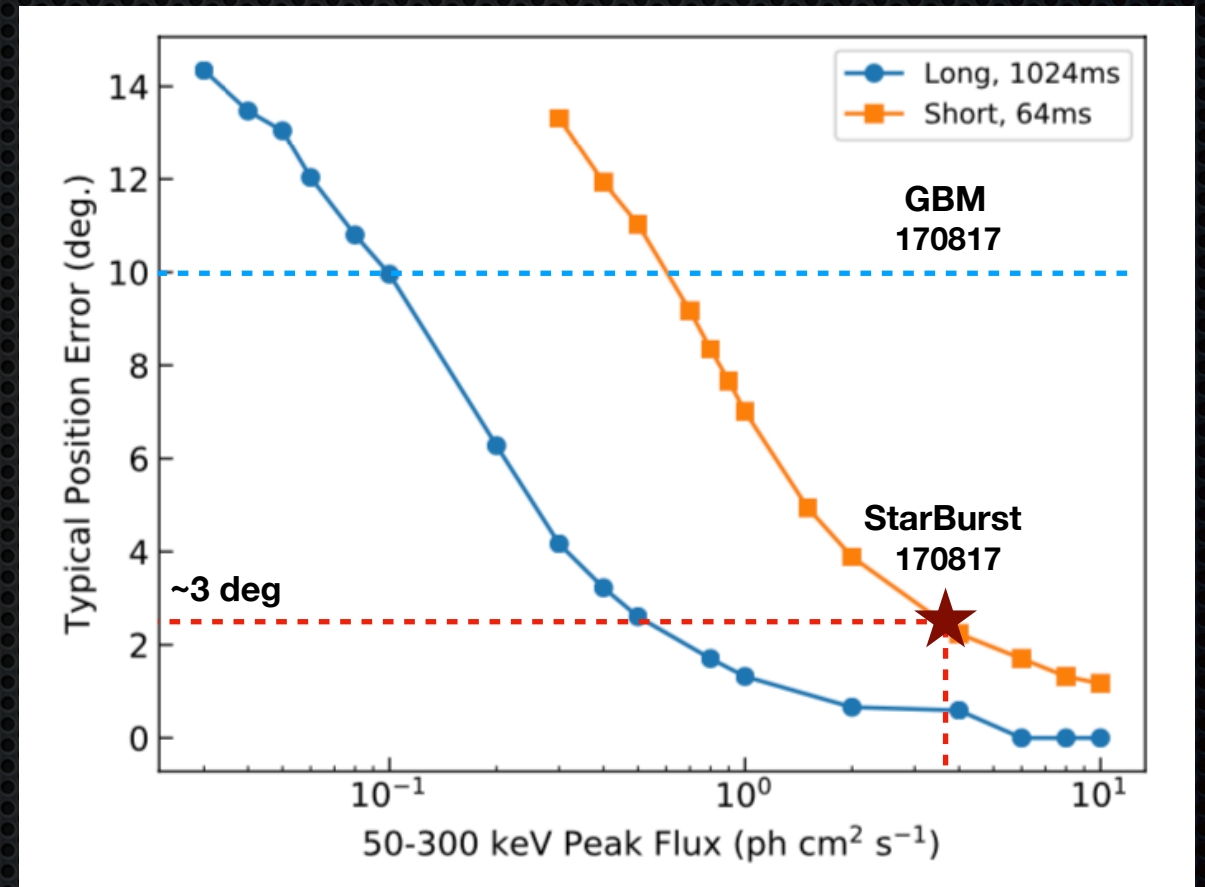
- ✦ Based on model developed by E. Howell et al (2018)
- ✦ Roughly 3.7% of the median A+ BNS detection rate
- ✦ Median rate of 9.8 GW-SGRBs/yr (2.6—25.2 @ 90% CL)



StarBurst Performance

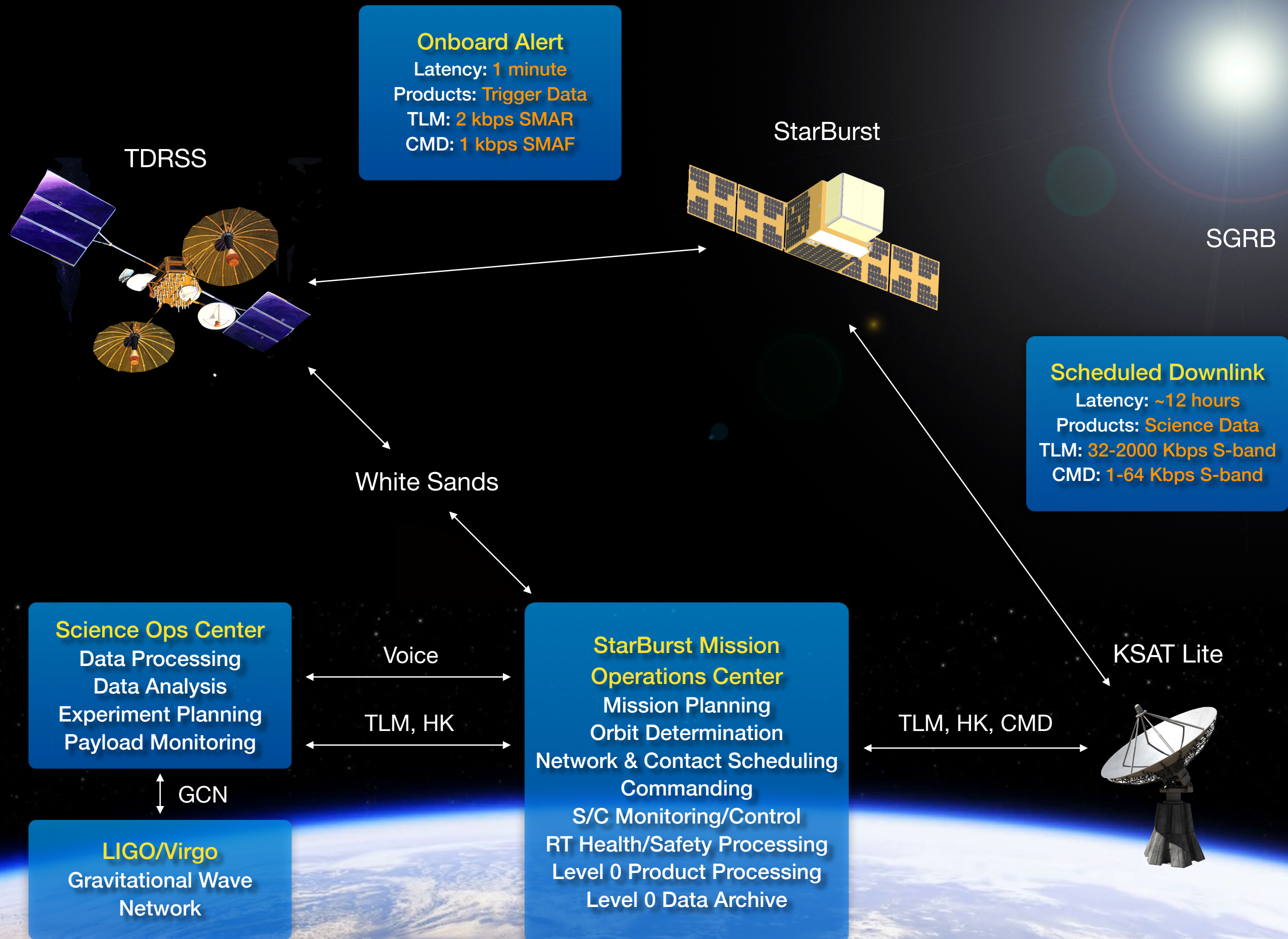


Detection Efficiency



Localization Capabilities

- GRB 170817 could be localized to within 3 deg, compared to ~10 deg with GBM
- Majority of bursts will always be near our detection threshold, so average is same as GBM



Early Career Scientists

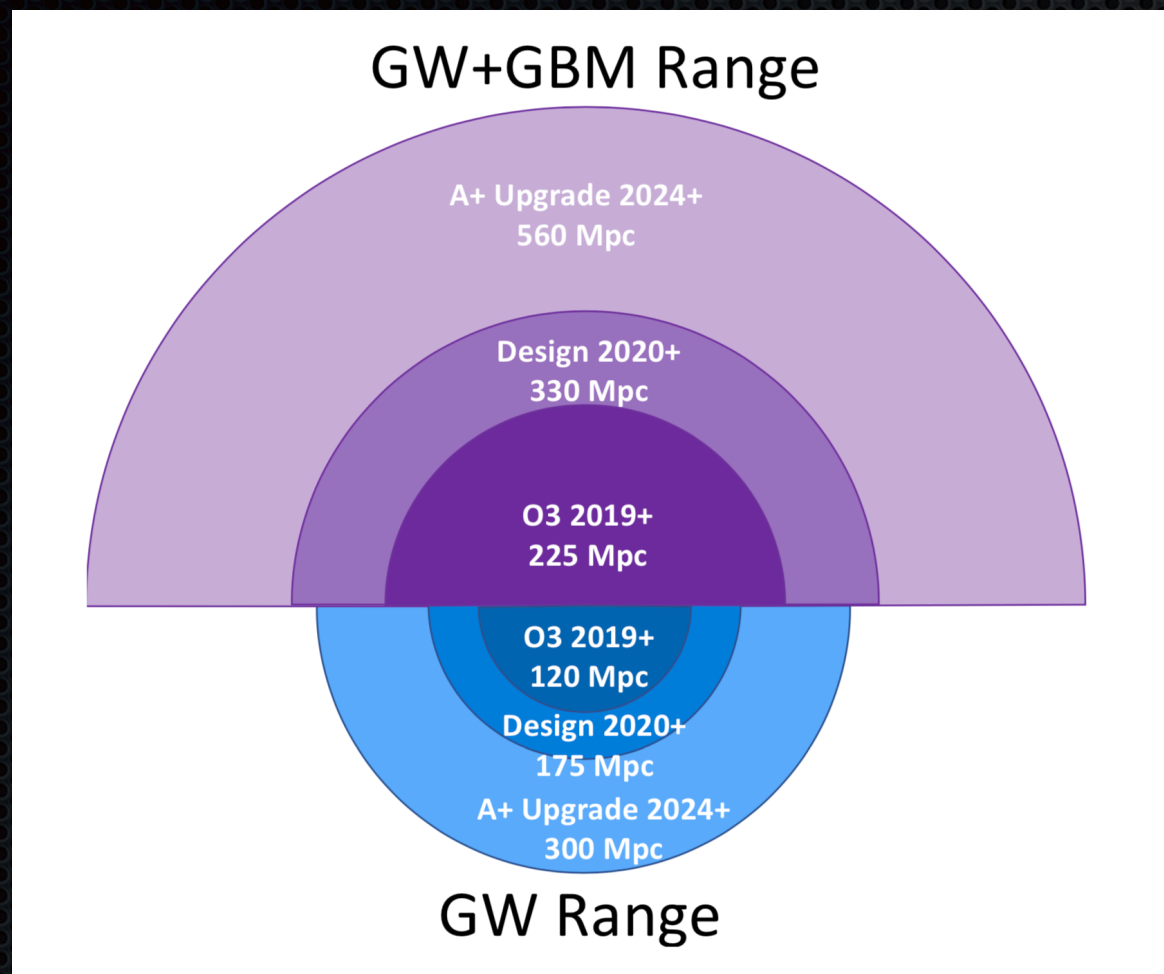
- ✦ Pioneers program evaluation criteria:
 - ✦ 50% Science, 25% tech development, and 25% advancing early career researchers
- ✦ StarBurst has over 10 early career researchers
 - ✦ 5 Early Career Doctorates
 - ✦ 4 Postdocs
 - ✦ 2 Graduate students
 - ✦ 2 Undergraduate students
- ✦ Strong mentorship roles
 - ✦ Several PIs with decades of experience are serving as mentors to the project team
 - ✦ Dr. Colleen Wilson-Hodge - PI of Fermi-GBM
 - ✦ Dr. Eric Grove - PI of Glowbug

StarBurst Phase-A Status

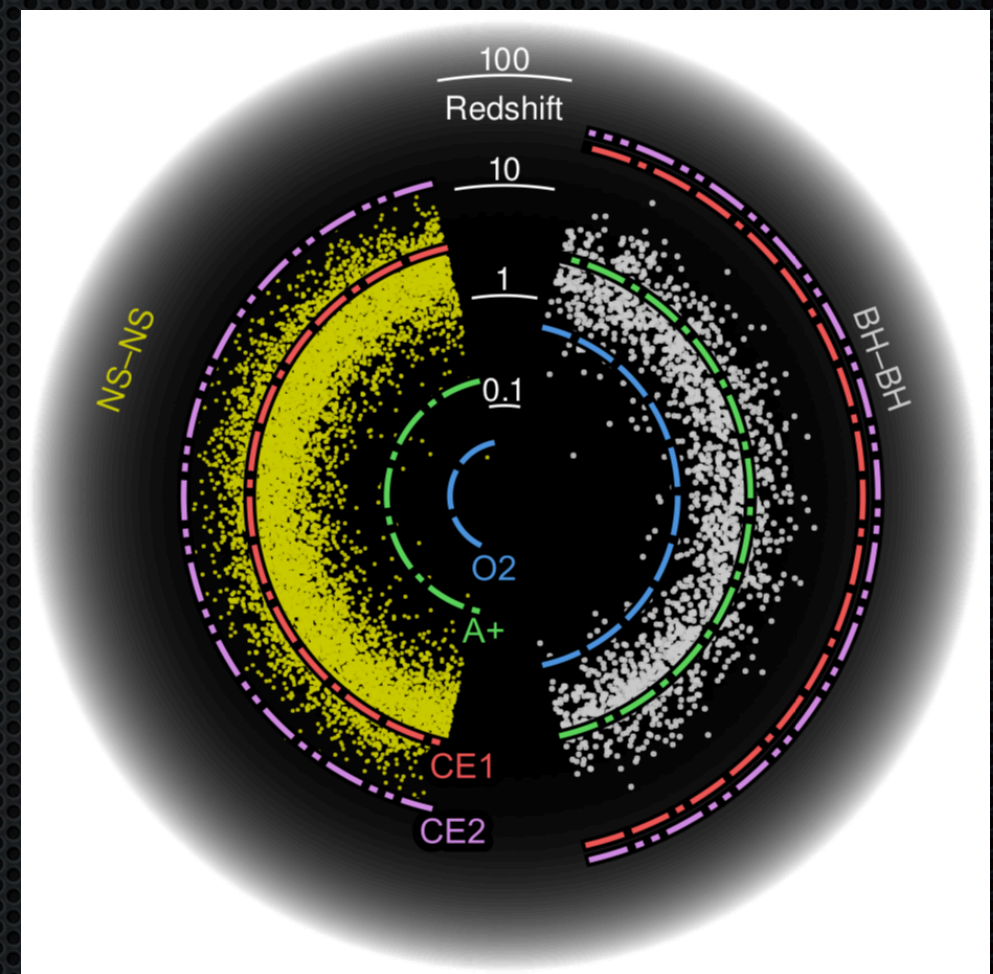
- ✦ Funding received and contracts in place
 - ✦ Naval Research Laboratory (NRL) IAA in-place
 - ✦ Space Flight Laboratory, UAH, and USRA funding has been provided
- ✦ Concept development work underway
 - ✦ Level 1 and level 2 Science Requirements have been finalized
 - ✦ Finalizing instrument block diagrams and concept of operations
 - ✦ Driving level 3 requirements currently being defined
- ✦ Formulating our internal mission schedule
- ✦ Currently formulating our integrated budget
- ✦ Engaged with the NASA SCan office to develop communication strategy
- ✦ CSR kickoff planned for July 23rd, with delivery on Oct 1st, 2021

Backup Slides

Fermi GBM + LIGO/Virgo



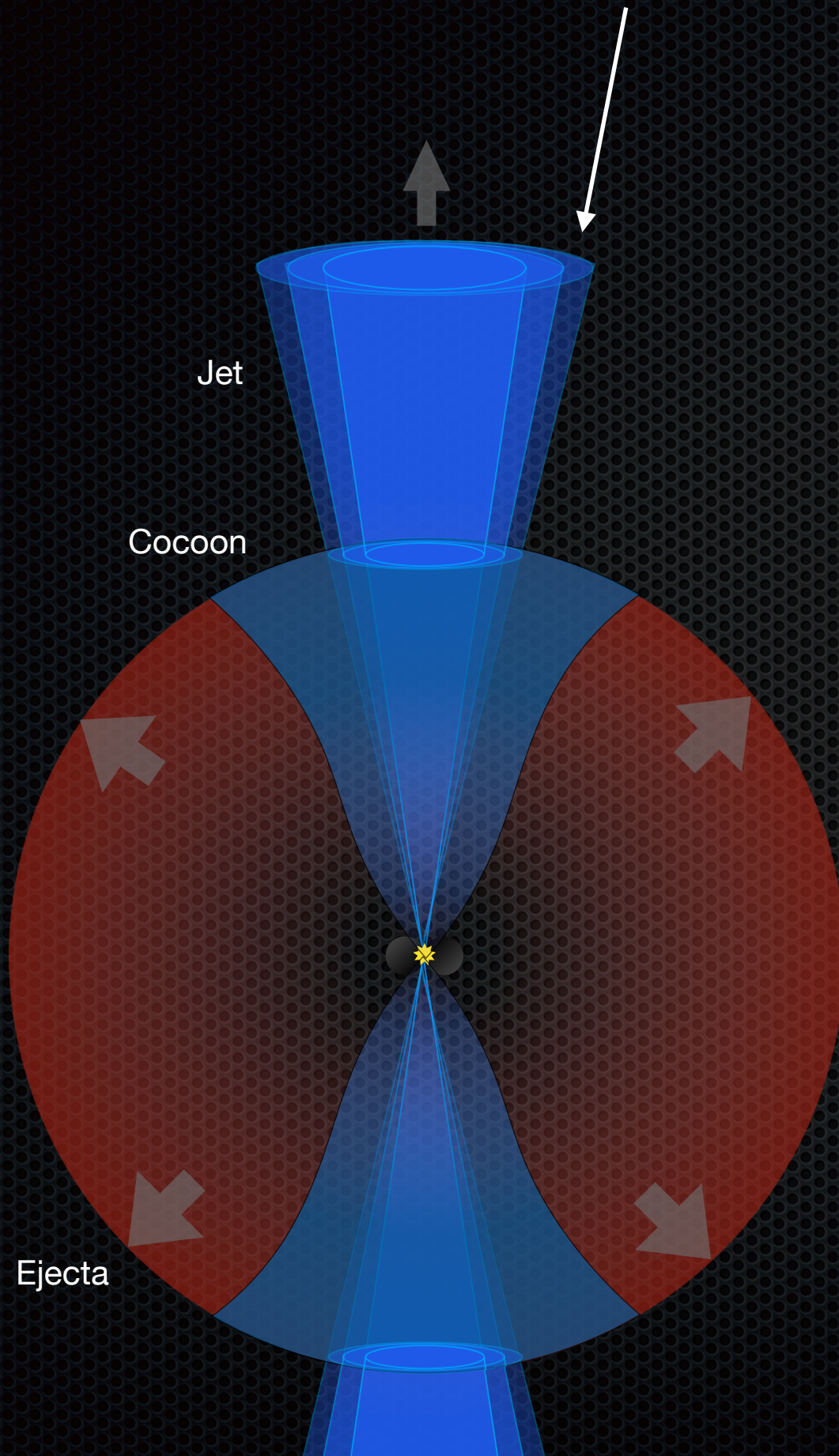
Gravitational Wave Horizon



Predicted Source Population

- Gamma-ray detectors provides increased confidence to weak GW detections
- Net effect is to increase the volume of the Universe accessible to GW detectors

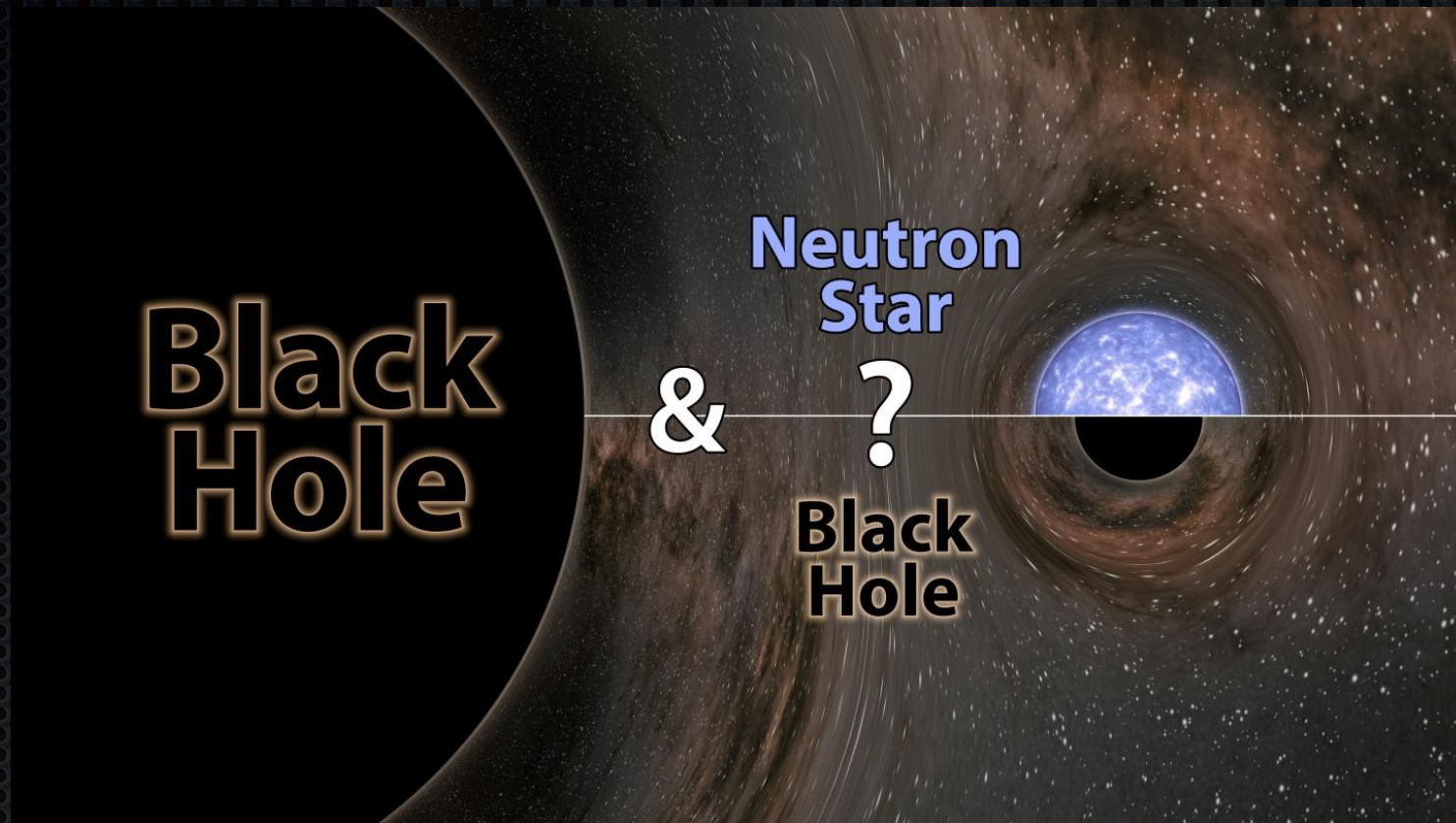
Off-Axis Structured Jet sGRB



Off-Axis Structured Jet sGRB

- We observed the less energetic region of a structure jet where the Lorentz factor decreases with θ_v
- Supporting Evidence
 - Could produce arbitrary E_{pk} and E_{iso} values
 - GW-EM delay is on the order of T_{90}
 - UV bright kilonova followed by infrared kilonova
 - Afterglow peaked and faded as the jet decelerated and we saw the more energetic core region of the jet
 - VLBI imaging revealed proper motion of the jet
- Open Questions
 - Not entirely clear how such wings are generated or what their Lorentz profiles look like
 - On-axis E_{iso} would still need to be relatively low

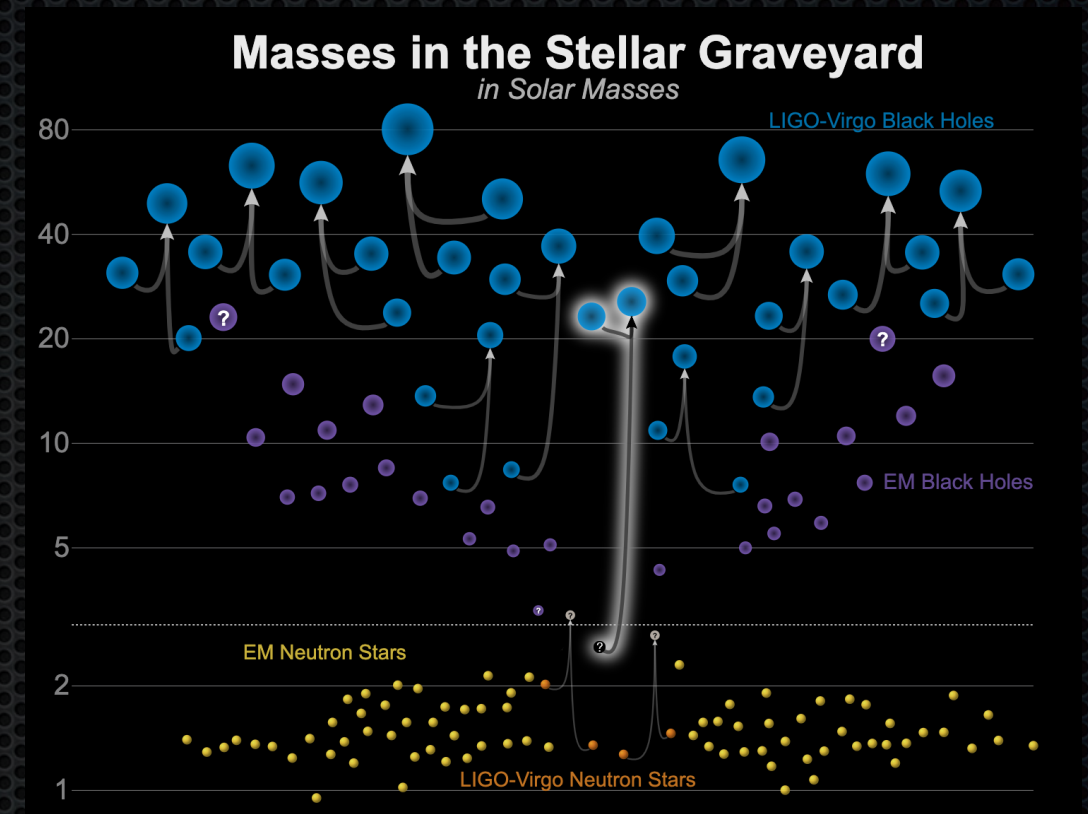
Short Gamma-ray Bursts Progenitors



- GRB 170817 showed that binary neutron star mergers can produce SGRBs
- Do mergers of neutron stars and black holes also produce SGRBs?
 - What is their contribution to the SGRB population?
 - How do their properties compare to SGRBs produced in BNS mergers?
- What range of BNS or NSBH masses are capable of producing relativistic jets?

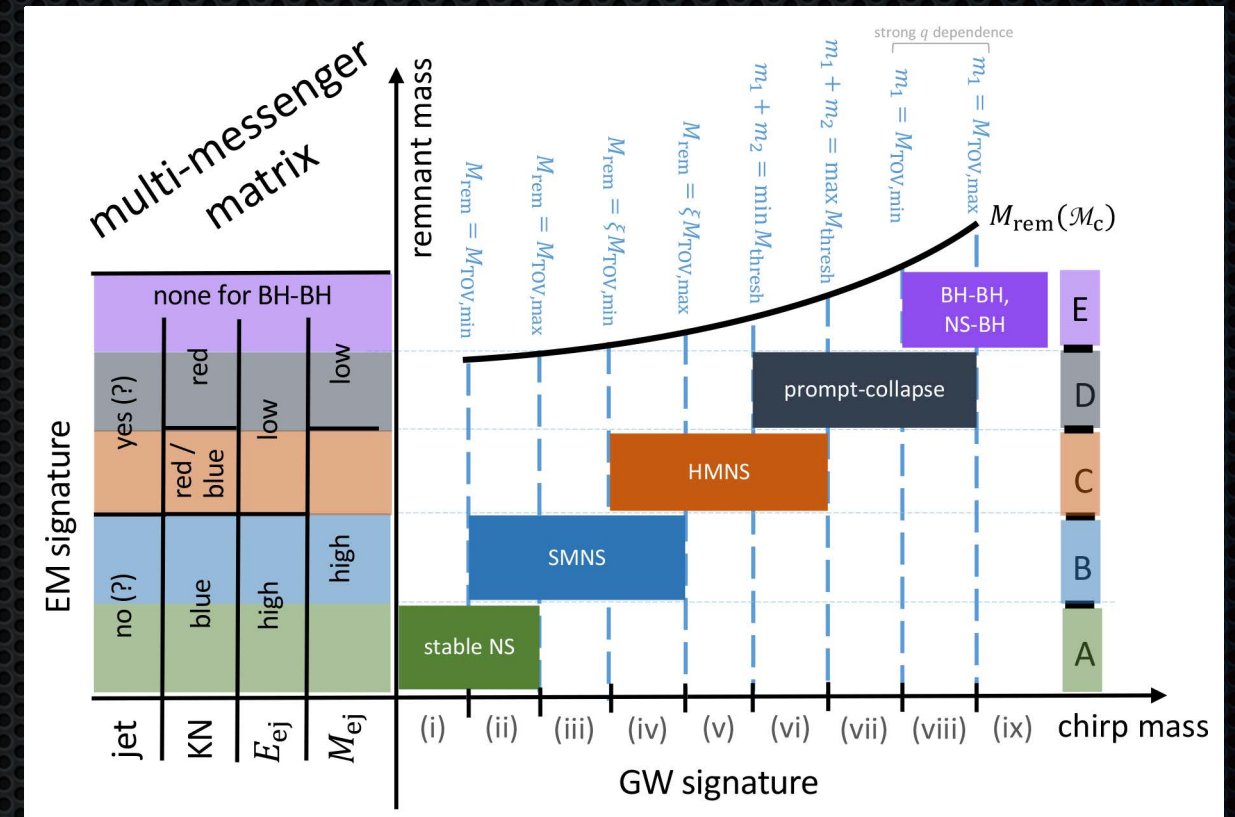
Curious Case of GW190814

- ✦ Candidate BH-NS merger system
 - ✦ $M_1 = 23.2 \pm 1.1 M_{\odot}$
 - ✦ $M_2 = 2.59 \pm 0.09 M_{\odot}$
- ✦ M_2 is either the lightest solar mass BH or heaviest NS ever discovered
- ✦ An EM detection can provide confirmation of the NSBH classification
- ✦ Would have immediate implications for the maximum neutron star mass (M_{TOV}) and/or BH growth models
- ✦ No EM counterpart detected
 - ✦ Distance = 241 ± 45 Mpc
 - ✦ Gamma-rays may be the most promising EM counterparts at these distances

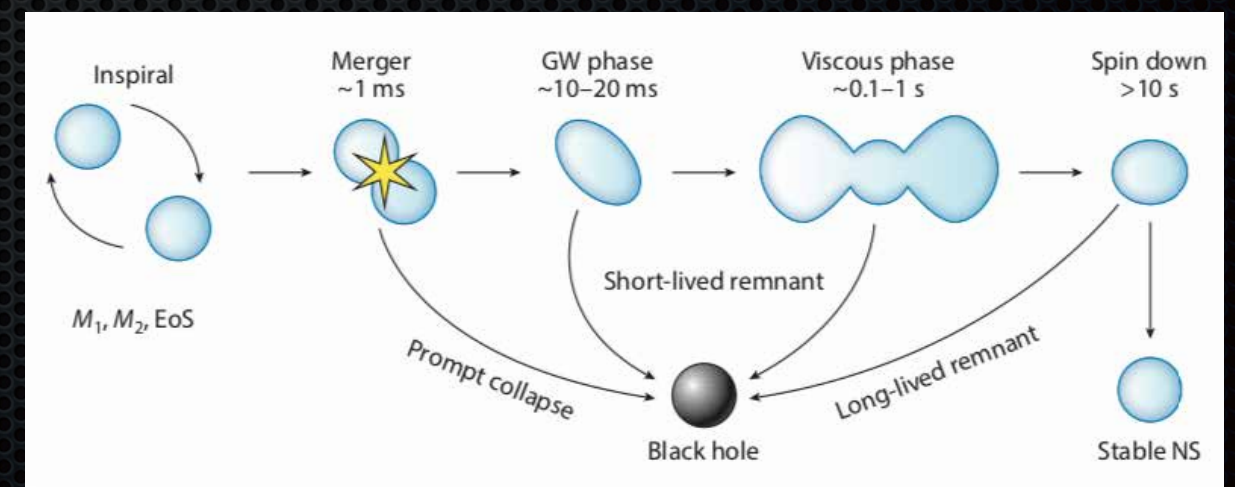


Merger Remnants and Central Engines

- A BNS merger can produce one of four possible remnants
 - Indefinitely stable NS
 - Long-lived supramassive NS (SMNS)
 - Short-lived hypermassive NS (HMNS)
 - Prompt BH formation
- Observations of EM counterparts for a range of NS masses can reveal which remnants can effectively launch relativistic jets
 - Mass transitions are uncertain and depend on the uncertain NOE and M_{TOV}
- Remnant determination may be possible with gamma-rays alone



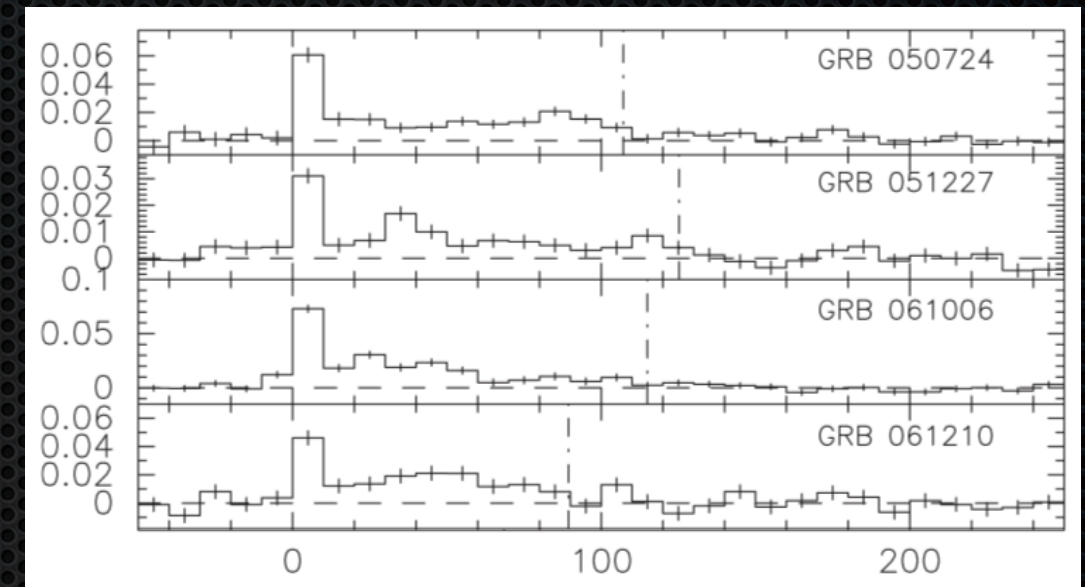
Margalit & Metzger (2019)



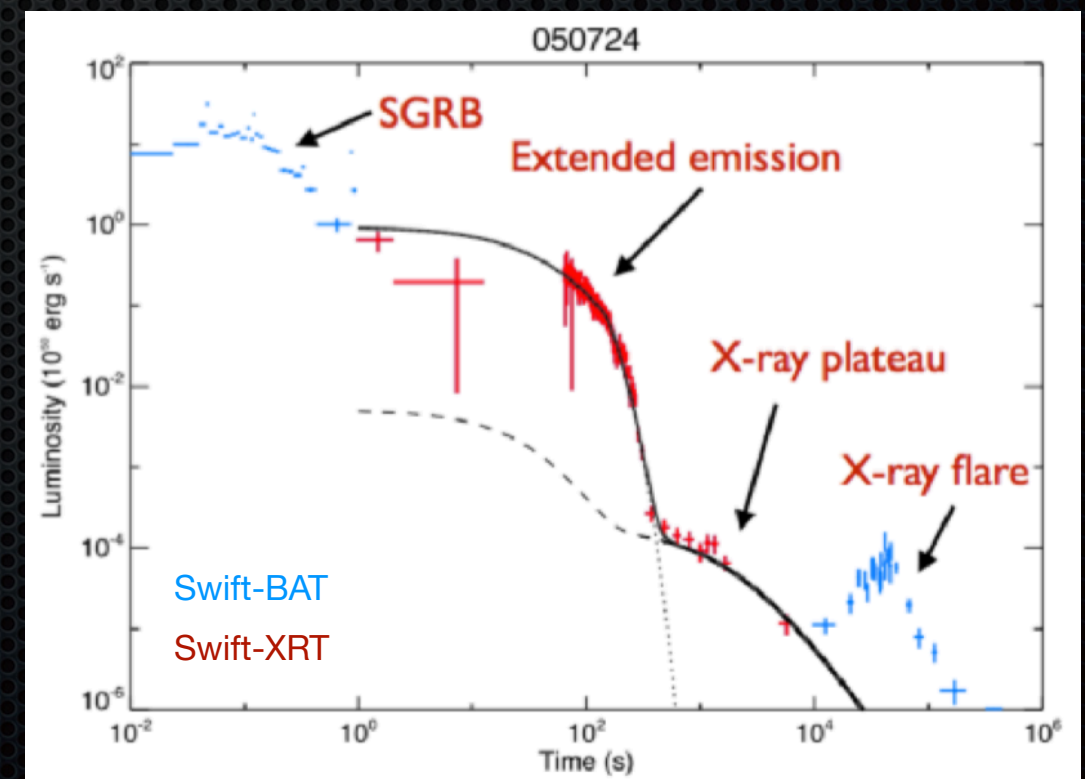
Radice et al. 2020

Merger Remnant Determination - Extended Emission

- Long-lasting gamma-ray plateau lasting ~30 seconds following a SGRB
- Observed to in roughly 20% of SGRBs
- Attributed to energy injection from long-lived magnetar remnants
- Extended emission in coincidence with a low-mass merger would point to a stable remnant or a SMNS
- Confirm that magnetar central engines are capable of powering relativistic jets
- Extended emission never accompanies low-mass mergers would indicate black hole remnants are a key to launching relativistic jets
- Sharp cutoff in the extended emission could provide insight into the remnant lifetime

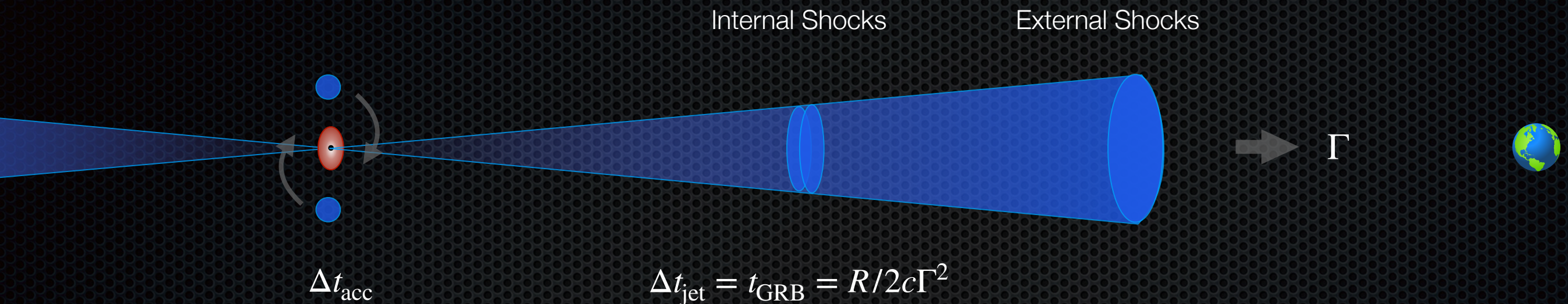


Sakamoto et al. 2011



Ciolfi 2017

Merger Remnant Determination - Delay/Duration



- The delay between GW trigger and the EM signal is the sum of the time it takes the remnant to launch the relativistic jet, the time for the jet to travel to a radius where the energy is dissipated

$$\Delta t_{\text{delay}} = \Delta t_{\text{acc}} + \Delta t_{\text{jet}}$$

- A GRB pulse duration depends on both the radius at which the emission originates and the time that the central engine is active, e.g. the accretion timescale.
- If $\Delta t_{\text{delay}} \sim t_{\text{GRB}}$, then $\Delta t_{\text{acc}} \rightarrow 0$, pointing to a short lived (< 0.1 sec) HMNS or prompt collapse to BH
- If $\Delta t_{\text{delay}} \ll t_{\text{GRB}}$, then $\Delta t_{\text{acc}} > t_{\text{GRB}}$, pointing to a long-lived (~ 1 sec) HMNS remnant
- If $\Delta t_{\text{delay}} > 1\text{s}$, points to a long-lived SMNS which remains supported against collapse after rigid body rotation

Structure of Relativistic Jets

- GRB 170817A was notably under-luminous compared to the population cosmological SGRBs
 - Naturally led to an “off-axis” interpretation
- The jet structure that would allow for such off-axis emission is highly uncertain and unconstrained
 - Joint GW-EM detections with known inclination angles can probe the angular profile of structured jets
 - 25 EM observations of GW-detected NS mergers (including non-detections) could constrain the width of a Gaussian jet to a few degrees (Hayes et al. 2020)
- Cocoon shock breakout could also produce EM emission
 - A measure of the temporal properties of the gamma-ray emission could discriminate between cocoon and structured jet
 - Observations of cocoon emission could help place constraints on the extent of the merger ejecta

